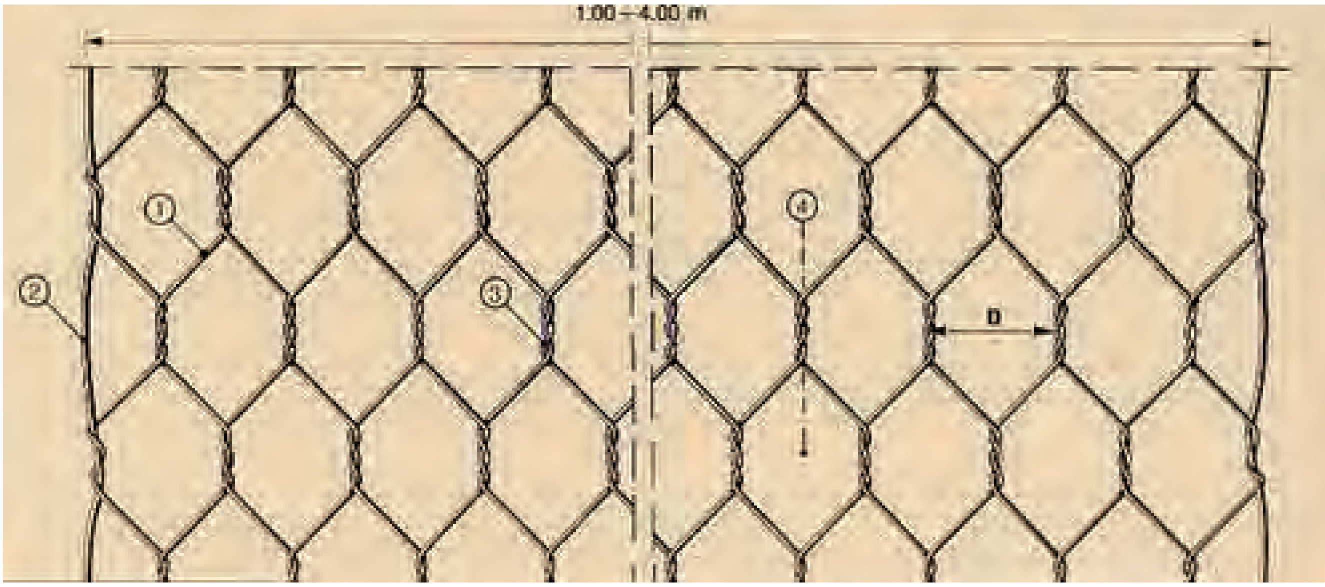
Edwin Fecker

Report on Rock Mechanical Aspects Concerning the Eastern Buddha Niche, 2006

When creating sculptures in stone the artist has generally the possibility to take a perfect block from a quarry, from which he can in his experience create the desired sculpture. This is not the case for sculptures which are built out of the in-situ rock. If so, the artist has to take the conditions of the different rock structure and the discontinuities for granted and he has to integrate them into his sculpture. This is especially valid for sculptures with the dimensions of the Buddhas of Bamiyan, where a permanent rock alternation is observed over the total height of 40 resp. 60 m and where the discontinuities are setting limits to the sculpture.

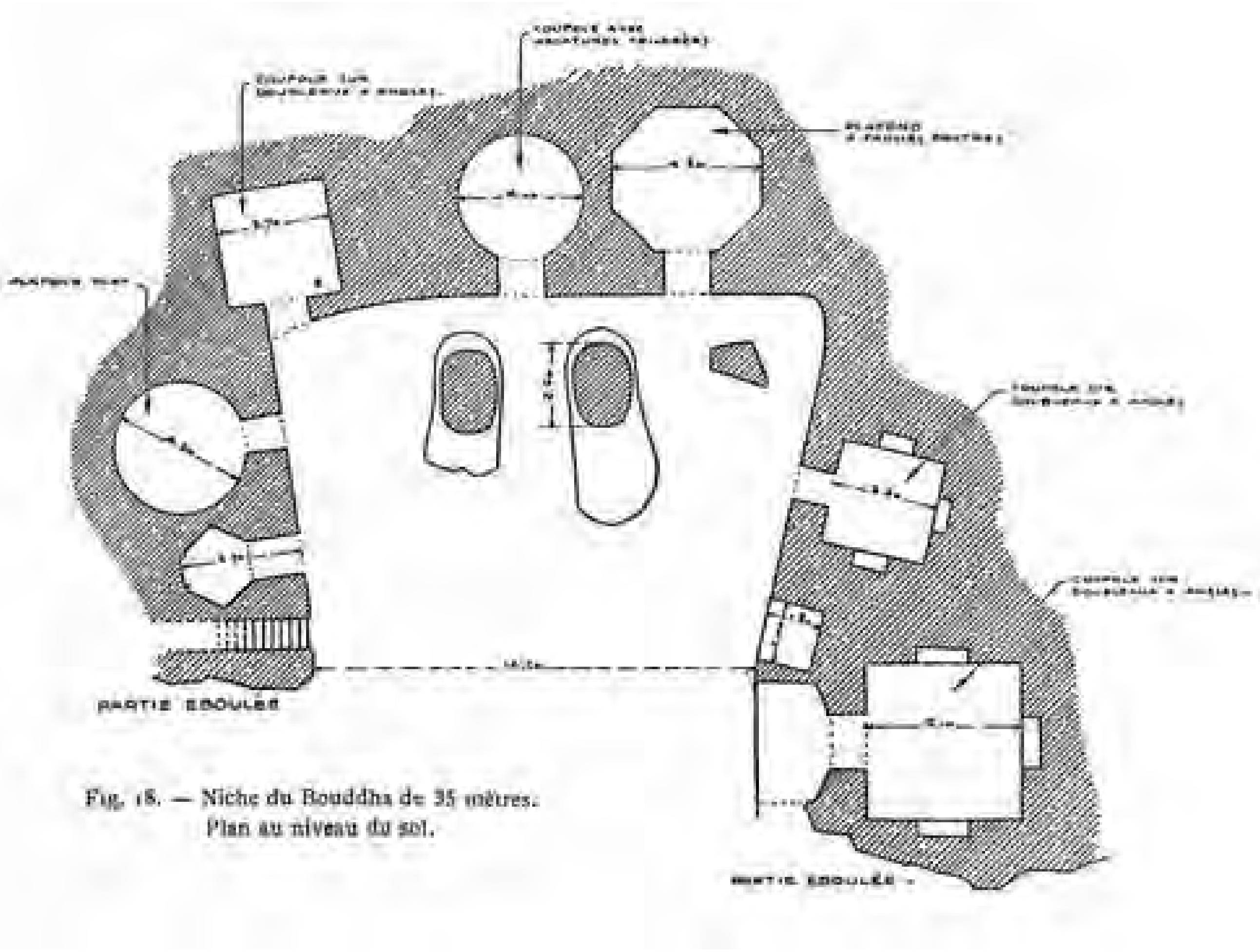
Furthermore geological processes, which take place in every valley more or less quickly, are naturally influencing the structures embedded in valley flanks, too. Today the geological processes have built a cliff which is rising nearly vertically between 100 and 150 m high from the Bamiyan Valley. Due to the gravity tension joints parallel to the slope, open on top, are created in such an oversteeped valley. The result is that 10 to 20 m thick slabs of the cliff wall are toppling or parallel to joints large parts of slabs are collapsing, e.g. due to earthquakes. At the cliff of the Eastern Buddha, being about 500 m long and 100 m high, a rock fall and

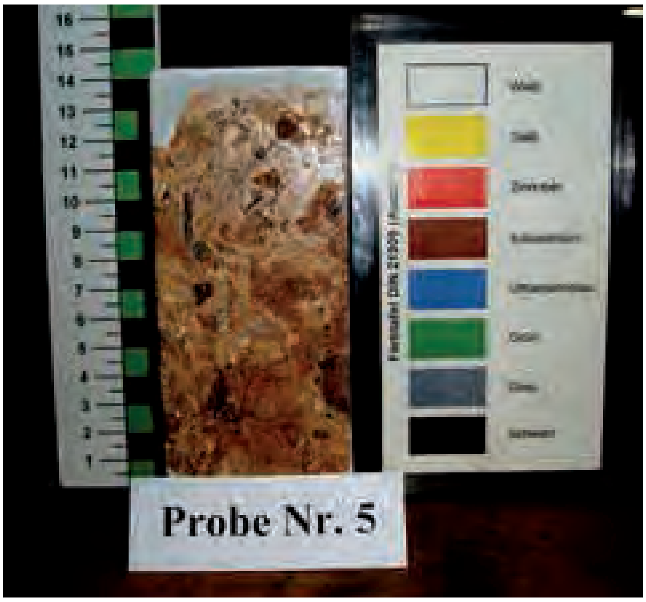
Eastern cliff of the Bamiyan valley with the niche of the Eastern Buddha. At the foot of the cliff several rock masses from slope movements can be recognised.



Double-twisted hexagonal 8 x 10 type steel wire mesh. 1 mesh wire, 2 lateral wire, 3 double twist, 4 twist axis (www.hydrogeo.net/rete_doppia_torsione.htm)

Site plan of the niche of the Eastern Buddha (from Hackin and Carl, 1933)





Example of a test specimen prepared for a uniaxial compression test. The sample is sawn from a rock sample. The upper end surface is completed with plaster.

several other mass movements are well-cognizable; if they took place in historic times it must be reserved to more exact examinations and is not the subject of this report. What can be said about it in any case is shown in a comparison of today's situation with the drawing of Charles Masson from the year 1832 (see fig. 3, p. 20). In that drawing the most west sliding mass had not yet come off, so it must be younger than this year.

If the tension joints of the cliff pass the niche of the Buddha itself they are an aspect of global stability of the niche and may not be disregarded.

Another geological process which could influence the stability of the niche is weathering caused by precipitation. As the in-situ sedimentary rocks, mainly coarse-, mid- and fine- grained conglomerates and siltstones, do not have a very solid grain-to grain bonding they are weathering strongly when water is penetrating into their pores. Of course this circumstance must have been known to the builders of the Buddhas of Bamiyan, that's why they worked the Buddhas out of the in-situ rock in a 40 m high niche, so that they have not been exposed to precipitation.

For me it seems even probable that the water loosening of the rock has been taken as a working support when excavating the niche, the galleries and the caves, because there are no traces of treatment with hammer and wedge at the surfaces of the preserved fragments of the Buddha.

A second advantage is that the annual precipitation in the Bamiyan Valley is very low (according to http://www.klimadiagramme.de/Asien/bamiyan.html at present in average 133 mm/year), which is opposed to a fast weathering.

As a third fact the roof of the cliff is superposed by a big weathering layer which avoids that large water quantities are penetrating into the niches through the joints, but will evaporate partially or concentrate on the surface in channels and smaller gullies and will drain off. However, the geological processes have impaired the structure in the course of the centuries. Especially the channels which have transported the water from the superposed weathering layer to the cliff wall are the reason for natural destructions close to the niche, what led to considerable conservation measurements by archaeologists, restorers and engineers of the Archaeological Survey of India from 1969–1977.

But the most important destructions have their reason in the species *Homo Sapiens*. In the last centuries such interventions are documented repeatedly. They are culminating in the destructions of beginning of March 2001, when a strong explosive charge has been initiated in the middle cave behind the Buddha, which blasted the largest part of the Buddha and left a lot of local instabilities, which are subject of this report.

Geological Characteristics of the Niche

Subsequently the geological characteristics in the niche of the Eastern Buddha are described to provide the basis for continuing consideration. Some of this knowledge is based on former publications, some is based on my own studies. Furthermore I would like to refer that this theme is subject of studies of the Geological Institute from the University in Cologne where it will be described much more detailed. I'm only concentrating here on the geological aspects which are important for rock mechanic purposes.

Type of Sedimentary Rocks

In the area of the niche of the Eastern Buddha mainly conglomerates with different sized pebbles (coarse-, mid- and fine-grained) are present. The conglomerate layers are interrupted from some siltstone layers. The layers are inclined few degrees towards East. In the examined area of the niche they can simplified be taken as horizontally bedded.

Figure 1 shows samples of the conglomerate which contains fine-grained pebbles (samples no. 1 and 2).

Alteration of samples no. 1 to 5 under water after 24 hours.

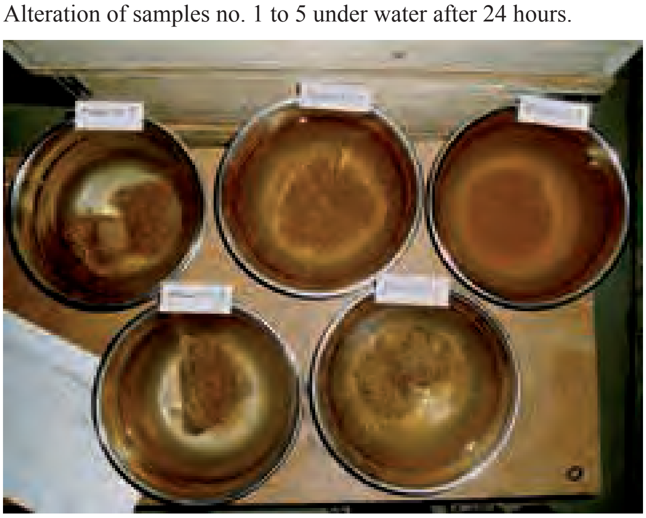


Figure 2 shows a sample of the siltstones (sample no. 3) and figure 3 a sample of the conglomerate with medium-sized pebbles (sample no. 5). The cementation of both rock types, conglomerates as well as siltstones, is not very strong and two of them (samples no. 3 and 4) do not contain cementing agents, that's why they totally decay in their individual grains in the case of water immersion. These rocks are only compacted by overburden, without a chemical cementation. The conglomerate of sample no. 5 seems to have at least a little cementation.

Grain Size

As we would not take rock samples from the back wall of the niche we collected the above mentioned samples underneath the niche (sample no. 1 to 5, figs. 1–3). It is not sure that they come from the niche of the Small Buddha, but I do not consider this to be essential, because for the conclusions that are drawn from the examination it is not relevant if the samples are from the niche or close-by. The grain size distribution of the samples is shown in figures 4–7. To determine the grain distribution the samples have been stored under water for 24 hours. After this the percentage of the different grains composing the samples has been determined by sieving and sedimentation analysis. At sample no. 5 this method could not be used, because the alteration under water was moderate and the sample did not decay in its individual grains.

Density

In the niche of the Eastern Buddha siltstones and conglomerates with highly variable composition of the matrix and the pebbles are present. That's why larger variations are likely to occur as regards the density. From literature (Margottini, 2004) a natural density of $\rho = 2.28$ g/cm³ and a dry density of $\rho = 2.23$ g/cm³ is known for the siltstone.

The few samples which we have examined should give a first indication and are not exhaustive. The results are sufficient for the purposes for which this parameter is needed in our context. We have determined a mean natural density of $\rho = 2.00$ g/cm³ for the siltstone (sample no. 3), which corresponds to a specific weight of $\gamma = 19.62$ kN/m³. For the conglomerates (samples no. 1, 2, 4 and 5) we have determined a mean natural density of $\rho = 2.15$ g/cm³, which corresponds to a specific weight of $\gamma = 21.09$ kN/m³ (see figs. 8 and 9). The water content w of the individual samples is shown in figure 10. The water content is very low, which is why the dry density differs only marginally from the natural density.

Jointing

The main joint system in the niche of the Eastern Buddha is parallel to the valley which runs at this point in near East-West direction. Due to the explosion of March 2001 the new formed discontinuities do not follow the rules for naturally created joints. Indeed the new formed back wall of the niche runs nearly parallel to the valley, but compared with a natural joint it is very irregular. That's why we cannot indicate a single value for the spatial position as usual.

From the back wall of the niche a topographic record has been made by a scanner in October 2006. For future support measurements this record is a much more exact basis than describing the back wall with a mean spatial position. This is also valid for the new smaller discontinuities which additionally separate the back wall of the niche and the caves at the base of the niche.

Earthquakes

Bamiyan is located on the Herat fault, a 1200 km long, east-west suture through central Afghanistan, that trends northward into the Hindu Kush mountains north of Kabul at its eastern end. The Bamiyan region is located in the transition zone between the intense seismic activity that characterises the Indo-Asian continental plate boundary in eastern Afghanistan, and the largely inactive central part of Afghanistan. Written records of historical earthquakes in Afghanistan are sparse. Even in the 19th and early 20th century communications remained poor due to the skeletal development of roads, phone lines and government infrastructures, resulting in few published notices about earthquake locations and damage. Historically, the western Herat fault has remained largely inactive; however, a significant earthquake occurred near Bamiyan on June 9th, 1956. The causal fault that slipped in this M = 7.4 earthquake is not known although it appears to have occurred in the region bounded by the Herat fault and the Andarabad fault, 80 km to the north of Bamiyan in the Sadat valley (see Ambraseys & Bilham).

According to Reineke (Bamiyan Masterplan Campaign 2005) an earthquake was registered located west of Bamiyan with a magnitude of M = 4.9 in May 28th 1997. As a result of these earthquakes the region belongs to the moderate dangerous places in Afghanistan. The danger of mass movements (rockfall, mudflow etc.) triggered by tectonic events is, compared with other regions in Afghanistan, low but evident (see fig. 11 taken from USGS). Comparing the seismicity of this region with Germany it becomes apparent that however we are concerned with a relatively active earthquake zone. There is no zone in Germany with earthquakes with a magnitude of 7.4. In Germany earthquakes with a magnitude 7 and more are not at all to be expected. If an anastylosis of the Small Buddha is provided, a ground acceleration of 1.6 to 2.4 m/sec² due to earthquakes must be taken into consideration.

Mechanical Rock Characteristics in the Niche

The mechanical properties of the rocks in the niche have not yet been explored in detail. Margottini (2004) has executed some Schmidt-hammer tests to estimate the uniaxial compressive strength of the rocks. From the tests he has derived 30 MPa for the conglomerates and 36 MPa for the siltstones. Such tests are only index tests which are used for a first orientation. That's why we have decided to analyse the rock material from the area of the Eastern Buddha in the laboratory.

Uniaxial Compressive Strength

From the rock samples which we collected underneath the niche of the Eastern Buddha the Institute for Soil and Rock Mechanics of the Technical University Karlsruhe sawed out specimens to execute uniaxial compression tests.

The mean value for the uniaxial compressive strength of the conglomerate (samples no. 1 and 2) results in 2.99 MPa (see figs. 12 and 13). The value for the uniaxial compressive strength of the siltstone (sample No. 3) is 6.91 MPa (see fig. 14).

Sample no. 5, which concerns also a conglomerate, has – in contrary to the conglomerate of samples no. 1 and 2 – some cementation. The uniaxial compressive strength of this sample is 6.73 MPa (see fig. 15).

Weathering Resistance

As we already pointed out, the rock in the area of the Small Buddha niche contains only little or no chemical cementation. The grain-to-grain bonding is mostly a result of a mechanic compaction. The desintegration of the rock due to water susceptibility can be characterised by the alteration test under water according to DIN4022, part 1 (see fig. 16).

For this test the samples are immersed into water for 24 hours and afterwards their alteration under water is determined or it can be demonstrated that they do not show any changes. This test is a characteristic for the content of chemical cementation.

The five samples that we have examined with this test show the following result: Samples no. 3 and 4 without cementation are intensely alterable during this test, samples no. 1 and 2 are alterable and sample no. 5 is moderately alterable.

Also noticeable in the test result is the high water susceptibility of sample no. 3.

Stability Observations

Due to the explosion in March 2001 rock sections which have been partially loosened and are now on the verge of falling can be observed at the back wall of the niche of the Small Buddha and in the caves at the base of the niche. In case of a normal rock slope these rock parts would have been broken away.

I am describing them to give a decision-making-aid to conservationists for future measurements. If the costs would be the decisive factor, breaking off the loosened rock parts would be the cheapest solution by far. But if conservation aspects play the overriding role, technical solutions may and will be found to secure the loosened rock parts, which of course will be involved with higher costs.

Back Wall of the Niche

The back wall of the Eastern Buddha is still showing in its highest part rests of the head of the Buddha. This is a large rock plate which is affected in joints parallel to the slope by new formed ones (see figs. 17 and 18). The joints are slightly open. The whole part must be secured. I am considering the danger of larger rock falls in the near future to be low.

The right shoulder is affected in many parts due to several new formed joints parallel to the wall and loosened from the back wall (see fig. 19). Some joints are open. In my opinion the danger that some parts may fall down and the total section may follow is high. Especially caused by an earthquake – even of low magnitude – the section may lose its hold and fall down.

The left shoulder is also affected in many parts due to several new formed joints parallel to the slope and loosened from the back wall (see figs. 20–22). Some joints are open up to about 10 cm. In these open joints decimetre large rock pieces can be seen which have been fallen into the open joint from the upper side of the shoulder. Only a rock gusset of about 1.5 m² avoids the falling of the section. The rock gusset is also showing disintegration. In my opinion the danger that the whole part will fall is very high. Although this shoulder part seems to have been in the condition of a possible fall since 2001 we suspect that this part may fall even without the effect of an earthquake.

Underneath the right hand of the Eastern Buddha a dress pleat partially in good condition continues downwards which is slightly loosened from the back wall at the east edge below by some joints parallel to the wall (see fig. 23). The joints are scarcely open and seem to end under the pleat. I consider the danger of falling of this section to be very low.

Caves at the Base of the Niche

It was in the middle cave behind the feet of the Eastern Buddha (cave no. 5) where the explosive charge has been initiated. Hereby the partition walls to caves no. 4 and no. 6 as well as the front wall of all three caves were completely blasted out. Caves no. 4, 5 and 6 have a common ceiling now which is crossed by a newly formed gaping vertical joint (see figs. 24 and 25). This joint parallel to the slope extends only partially into the cave no. 6, and is feathering in the west wall of cave no. 6. In the east wall of cave no. 4 it is still some centimetres open. How it continues in the rock could not be found out with the available means.

As this joint runs parallel to the back wall of the caves and thus also parallel to the back wall of the niche it is no imminent danger for the stability of the back wall of the niche. It impairs at most the stability of the ceiling in the cave no. 5. The way I see it, there is no danger of collapse of this ceiling.

But there are some smaller rock plates which could fall down from the ceiling of the three caves. These plates have been temporarily supported with wooden beams. Later a final support measurement must be provided for them.

The other caves which are arranged around the niche (caves no. 1 to 3 and no. 7 to 8) have new formed joints, too – mostly in the ceiling. But the joints have no adverse effect on the stability. Only in cave no. 7 the ceiling is crossed by a net of new joints which could lead to smaller block falls. A final support measurement must be provided.

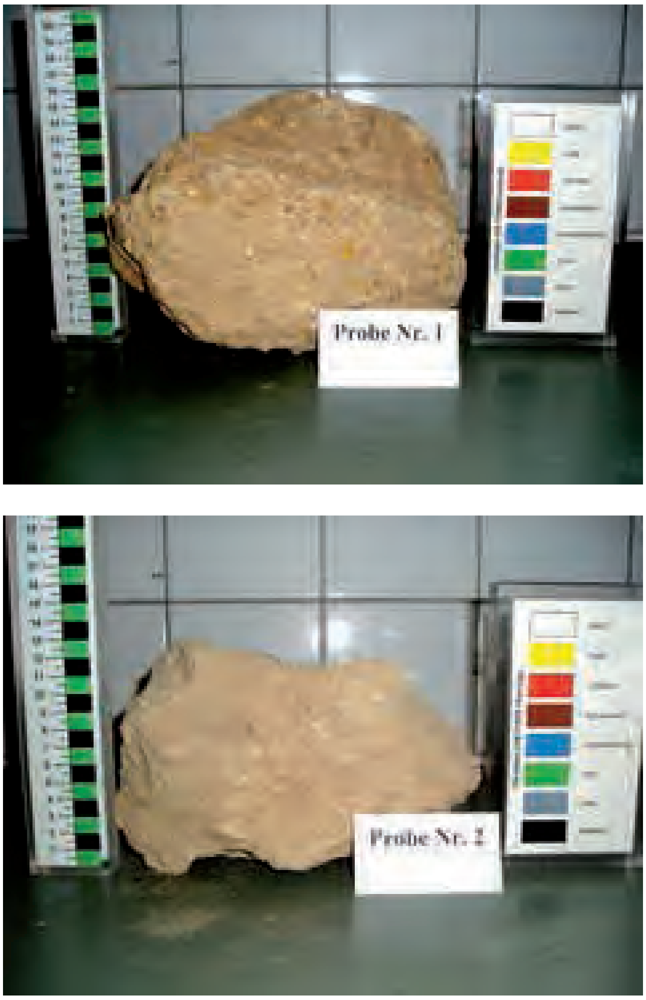


Fig. 1. Samples no. 1 and 2: fine-grained conglomerates

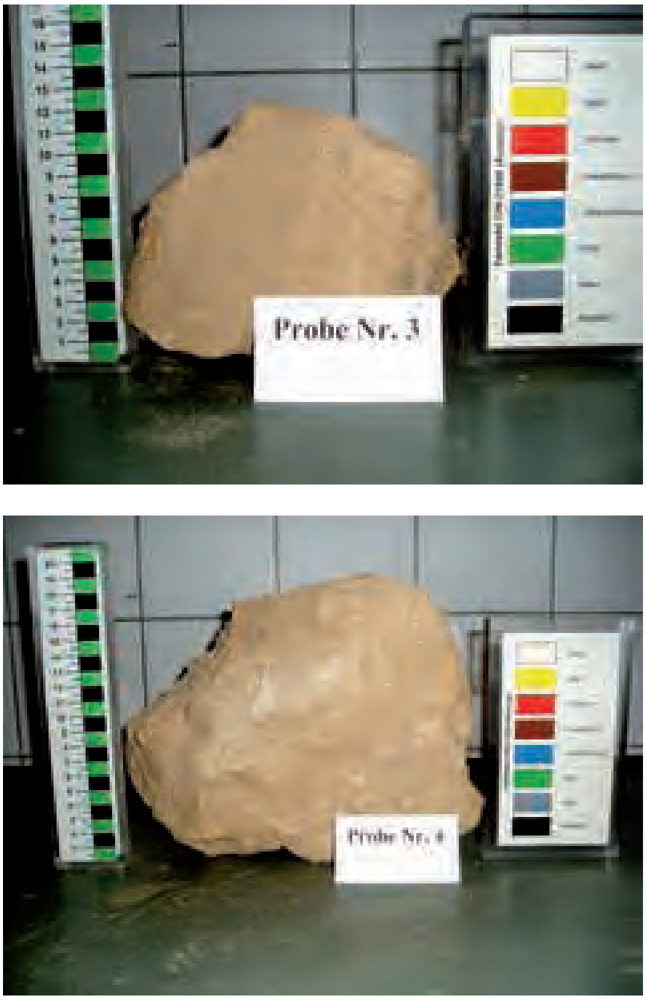


Fig. 2. Sample no. 3: siltstone; Sample no. 4: fine-grained conglomerate

Fig. 3. Sample no. 5: medium-grained conglomerate

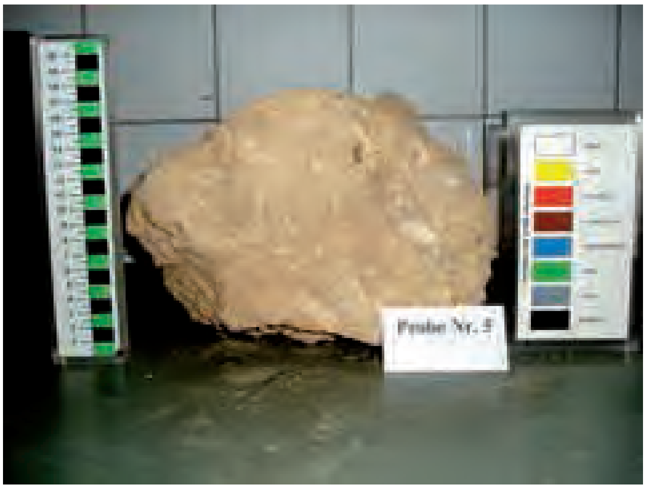
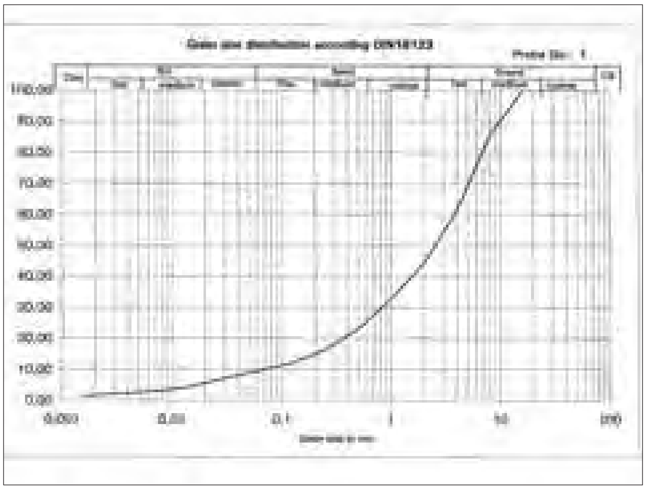


Fig. 4. Sample no. 1: grain-size distribution, according to DIN18123



Support Measurements

The support measurements for the back wall of the Eastern Buddha and for the caves at the base of the niche can be made in two steps. As first step the endangered rock parts must be supported at least in such a way that they are no danger for the persons who are entering the niche and the caves. The second step is to decide about a permanent support without or with the least interference with the historical substance.

Temporary Support Measurements

Since October 27, 2004, the back wall of the niche of the Eastern Buddha has been covered with a steel wire mesh to catch falling rock debris. It is a double-twisted hexagonal wire mesh with a mesh width of D = 84 x H = 121 mm, the diameter of the wire is 2.7 mm.

According to Muhunthan et al. (2005) this wire mesh is suitable to sustain rock impacts of 0.6 x 0.6 x 0.6 m pieces which are falling from the back wall. It will not be able to catch larger blocks. For double-twisted hexagonal wire mesh, impacts near the top of the installation should not exceed 10 kJ. Especially if the wire mesh does not sit snugly against the back wall larger blocks can fall free for several meters and get as much impact energy to break through the wire mesh (see fig. 26). Therefore, it is recommended to safeguard the wire mesh with steel wire ropes. Especially both shoulders should be crossed from several sides and the cross points should be connected with rope clips. The wire ropes (DIN3060, D = 11.0 mm) are to be well anchored on top and at bottom. How to do this without interfering in the historic substance can be decided on site.

The rock parts which are on the verge of falling from the ceiling of the caves no. 4 to 6 have been temporarily supported with wooden props in the meantime. When these props will be removed for a final support they have to be loosened with extreme attention. Removing the props is always much more dangerous than putting them up, because wedges are driven in when putting up the props. Hereby the supported plate may be moved and existing rock bridges may possibly be broken. When removing the props the rock part falls down.

Permanent Support Measurements

As I do not consider an interference in the historic substance desirable, e.g. by an anchorage of the dangerous rock zones in the back wall, I would like to propose a support measurement which would not influence the historic substance. The fundamental idea of this support is a steel girder construction which leans against the back wall and supports the dangerous rock zones by the retaining force applied to the back wall.

It would be self-evident to erect two vertical H steel beams at the point where the rests of both feet of the Eastern Buddha are located. The steel beams should have load distribution plates as contact surface which could be adapted to the feet surfaces. In the height of the beginning back wall, about 3.5 m above the bottom of the niche, a first crosslink between the vertical beams could be made where a support for the ceiling above niches no. 4 to 6 will be connected.

From the back wall area up to the shoulders both inclined beams could be connected by steel framework, which could serve as holding device for blasted parts of the Buddha body. A first draft of the framework is shown in figures 27 and 28.

Conclusions

Before executing further works in the niche of the Eastern Buddha I urgently recommend to increase the carrying capacity of the wire mesh by additional steel wire ropes. As a permanent support of the loose rock formations a fastening by anchors is imaginable. Alternatively, without intervention of the historical substance, I take a steel framework for suitable which leans against the back wall and serves as a support for the rock formations in danger of falling. At the same time this steel framework could be used as a load carrying system for a partial anastylosis.

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In 2006, the Institute of History of Art, Building Archaeology

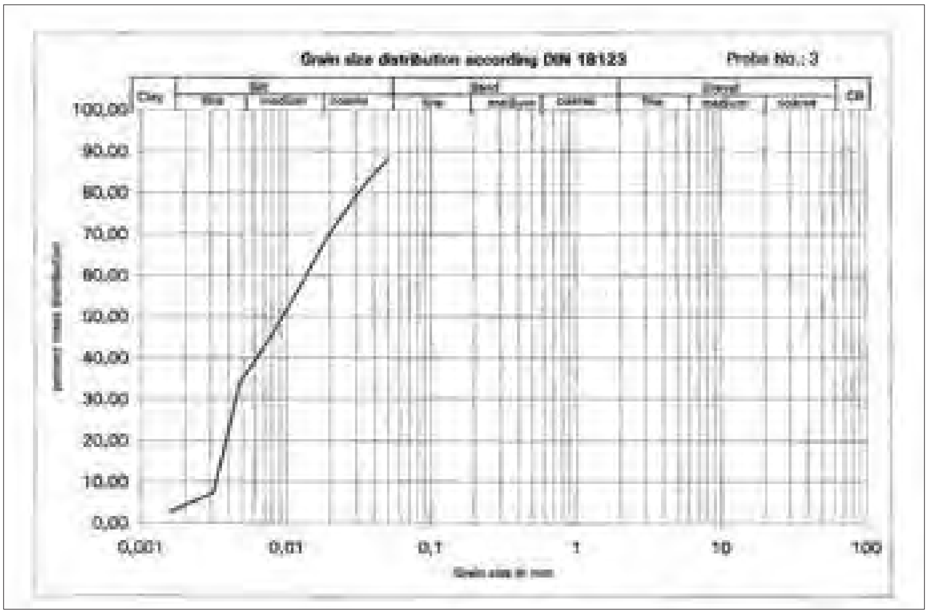

Fig. 5. Sample no. 2: grain-size distribution, according to DIN18123

Fig. 6. Sample no. 3: grain-size distribution according to DIN18123

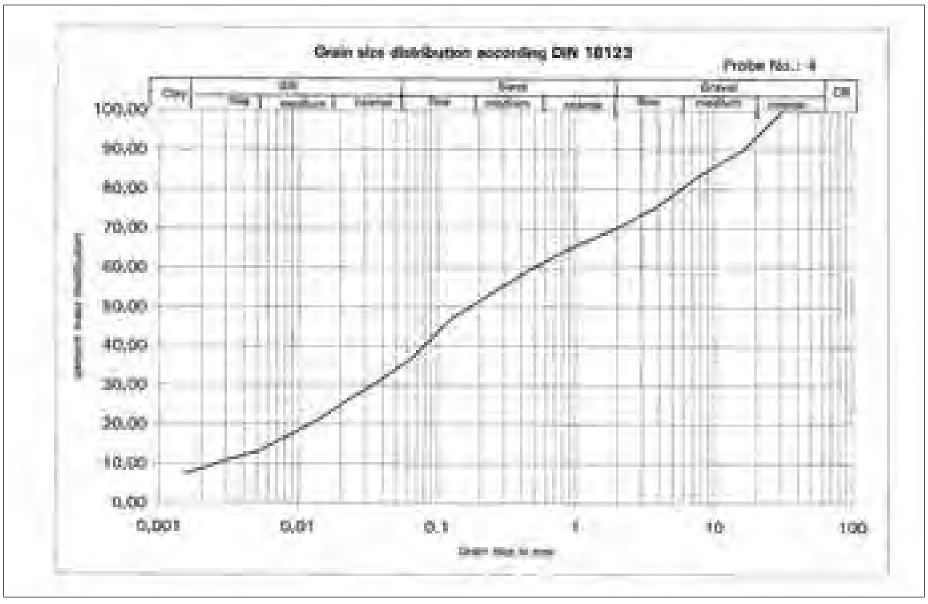

Fig. 7. Sample no. 4: grain-size distribution, according to DIN18123

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Density by Dipping and Weighing Method
according DIN 18125

Project:	Bamiyan	Project No.:	a-2682

Probe number:			Nr. 4	Nr. 3	Nr. 3	Nr. 1	Nr. 1
Depth: [m]							
Mass of wet material	m	g	332,9	188,2	212,4	356,0	634,8
Mass below water	m_u	g	176,8	95,1	104,9	195,8	348,7
Temperature of water	T	°C	20,0	20,0	20,0	20,0	20,0
Density of water	ρ_w	g/cm³	1,0	1,0	1,0	1,0	1,0
Volume of dipped probe	V	cm³	155,1	93,1	107,5	160,2	286,1
Tara Nr.							
Water content	w	%	1,6	3,6	3,6	0,7	0,7
Density	$\rho = \frac{m}{V}$	g/cm³	2,153	2,021	1,976	2,222	2,219
Dry density	$\rho_d = \frac{\rho}{1+w}$	g/cm³	2,119	1,951	1,907	2,207	2,203

Fig. 8. Density by dipping and weighing method, according to DIN18125

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Density by Dipping and Weighing Method
according DIN 18125

Project:	Bamiyan	Project No.:	a-2683

Probe number:			Nr. 2	Nr. 2	Nr. 5	Nr. 5	Nr. 4
Depth: [m]							
Mass of wet material	m	g	279,2	361,3	612,1	370,3	489,8
Mass below water	m_u	g	147,8	188,2	336,9	194,4	257,2
Temperature of water	T	°C	20,0	20,0	20,0	20,0	20,0
Density of water	ρ_w	g/cm³	1,0	1,0	1,0	1,0	1,0
Volume of dipped probe	V	cm³	131,4	173,1	275,2	175,9	232,6
Tara Nr.							
Water content	w	%	1,3	1,3	1,4	1,4	1,6
Density	$\rho = \frac{m}{V}$	g/cm³	2,125	2,087	2,224	2,106	2,106
Dry density	$\rho_d = \frac{\rho}{1+w}$	g/cm³	2,098	2,060	2,193	2,077	2,073

Fig. 9. Density by dipping and weighing method, according to DIN18125

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Universität Karlsruhe (TH)

Water content w
according DIN 18121

Project:	Bamiyan	Project No.:	a-2683

Probe number:	No. 1		No. 2		No. 3		No. 4		No. 5			
Depth: [m]												
Probe type:	Conglomerate		Conglomerate		Siltstone		Conglomerate		Conglomerate			
Container No.:	18	35	25	39	08	31	14	11	12	02		
$A = m + m_B$ [g]	1593,3	1259,7	879,6	770,9	571,9	994,1	1460,2	1165,3	984,4	1078,8		
$B = m_d + m_B$ [g]	1584,1	1252,2	871,0	763,1	560,8	966,2	1440,2	1151,3	975,1	1065,4		
$C = m_B$ [g]	232,0	237,5	228,6	224,4	235,4	224,2	225,5	226,1	235,9	225,9		
$m_w = A - B$ [g]	9,2	7,5	7,6	7,8	11,1	27,9	20,0	14,0	9,3	13,4		
$m_d = B - C$ [g]	1352,1	1014,7	642,4	538,7	325,4	742,0	1214,7	925,2	739,2	839,5		
$w = 100 \cdot m_w / m_d$ [%]	0,7	0,7	1,2	1,4	3,4	3,8	1,6	1,5	1,3	1,6		
Mean value: [%]	0,7		1,3		3,6		1,6		1,4			

Fig. 10. Water content w, according to DIN18121

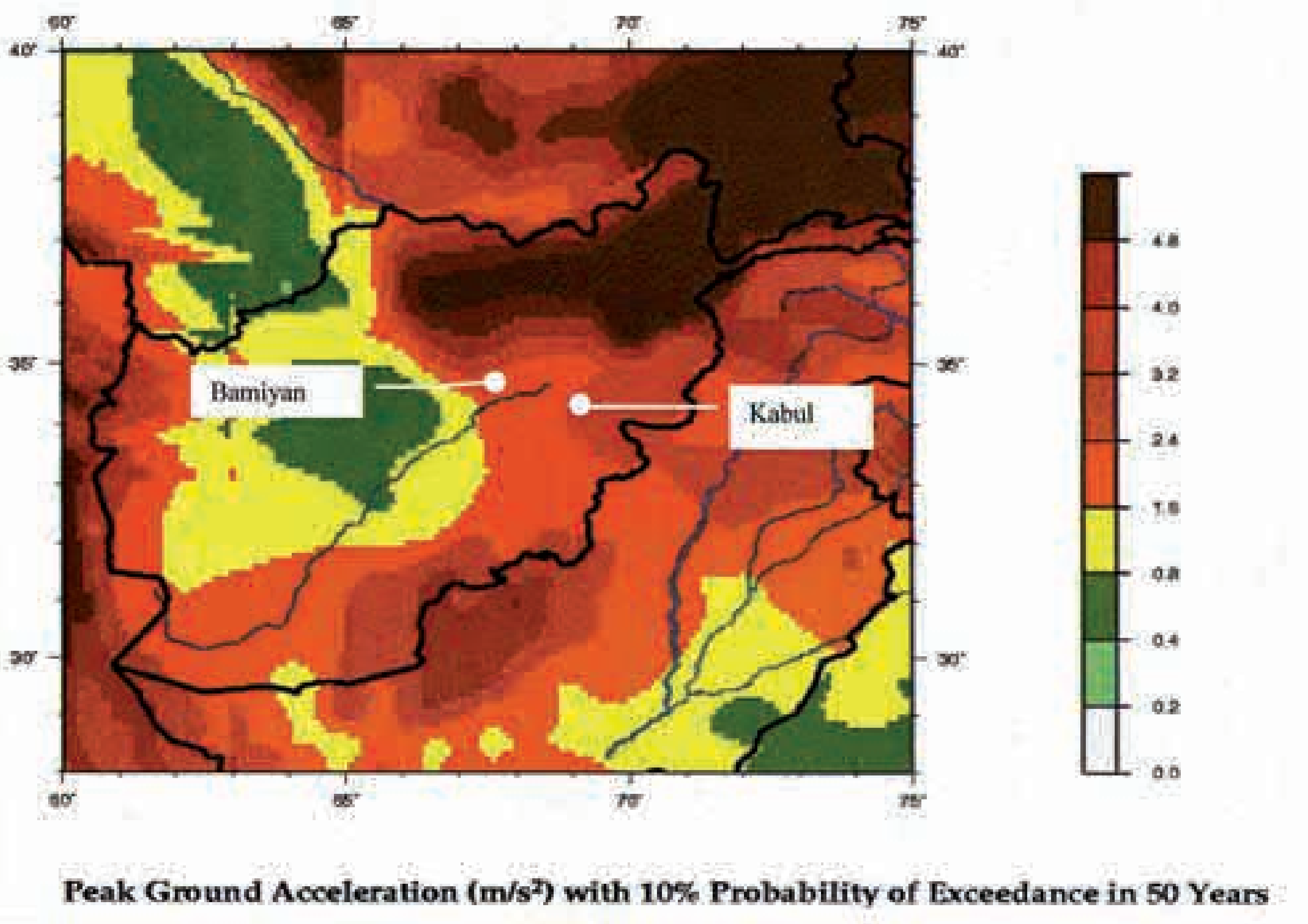


Fig. 11. Peak ground acceleration (m/s2) with 10% probability of exceedance in 50 years

Fig. 12. Uniaxial compression test sample no. 1 (conglomerate)

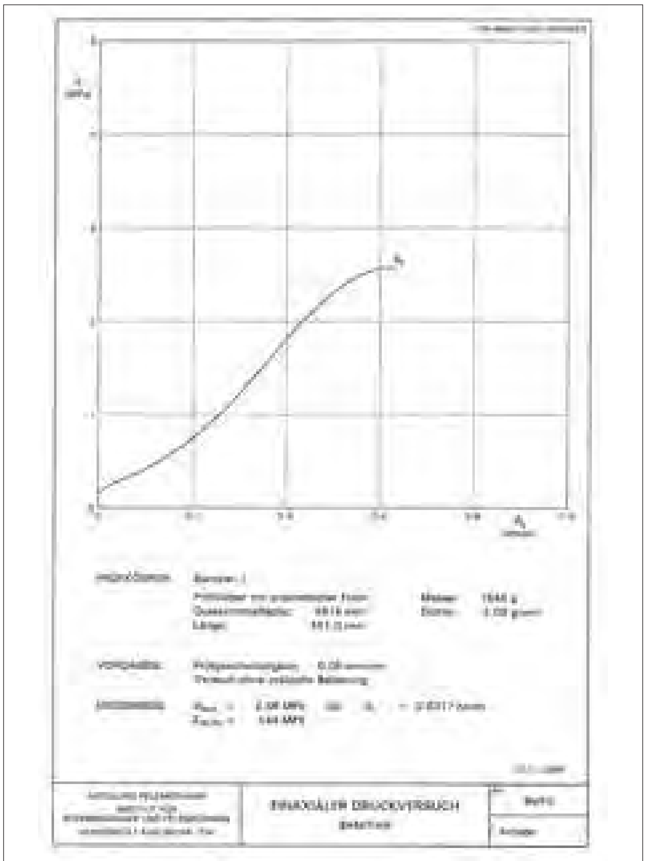
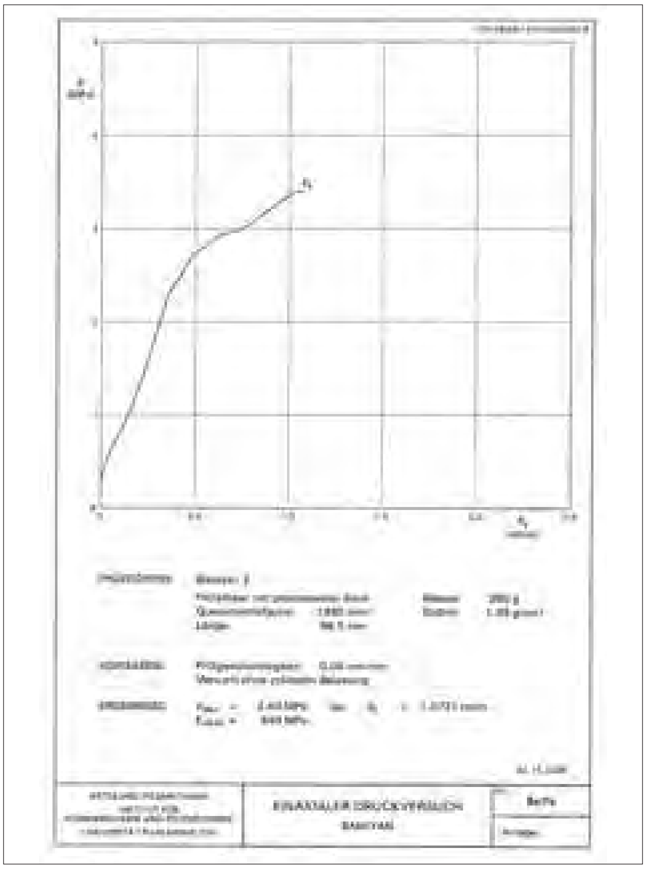


Fig. 13. Uniaxial compression test sample no. 2 (conglomerate)



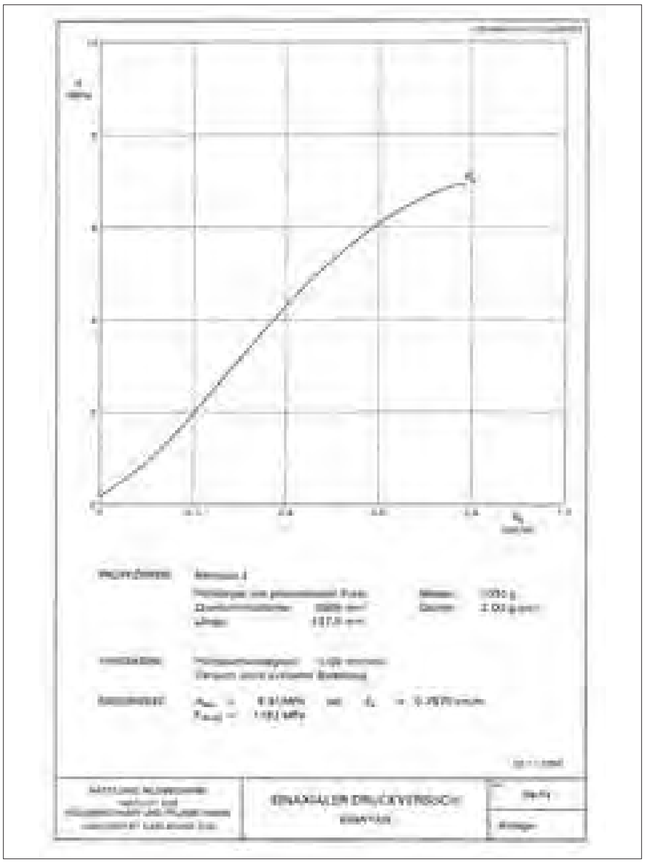


Fig. 14. Uniaxial compression test sample no. 3 (siltstone)

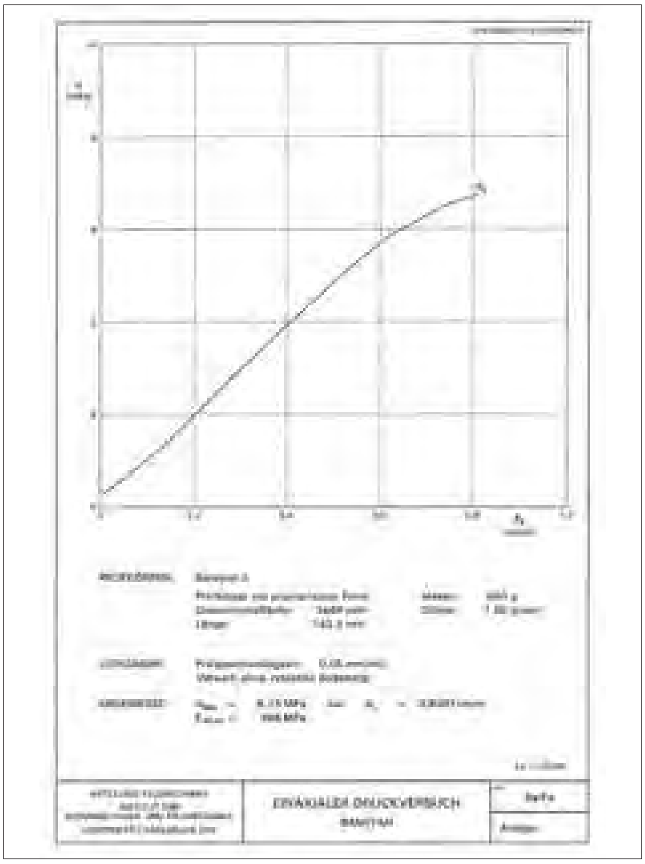


Fig. 15. Uniaxial compression test sample no. 5 (conglomerate)

Fig. 16. Alteration under water, according to DIN 4022 part 1

Abteilung Felsmechanik
Institut für Bodenmechanik und Felsmechanik
Universität Karlsruhe (TH)

Alteration under water
according DIN 4022, part 1

Project:	Bamiyan	Project No.:	e-2683

Test No.	Probe number	Depth [m]	Before test W1 [%]	After test W2 [%]	Alteration under water after 24 h: not alterable	moderate alterable	alterable	intense alterable
1	Probe No. 1		0,7	15,2			X	
2	Probe No. 2		1,3	24,9			X	
3	Probe No. 3		3,6	71,6				X
4	Probe No. 4		1,6	36,3				X
5	Probe No. 5		1,4	9,5		X		
6								
7								
8								

Not alterable: No probe changes determinable

Moderate alterable: Probe surface softened or parts crumble away

Alterable: Probe decayed, but component parts still solid

Intense alterable: Probe totally decayed and muddy

Fig. 17. Remains of the head of the Eastern Buddha

Fig. 20. Left shoulder of the Eastern Buddha

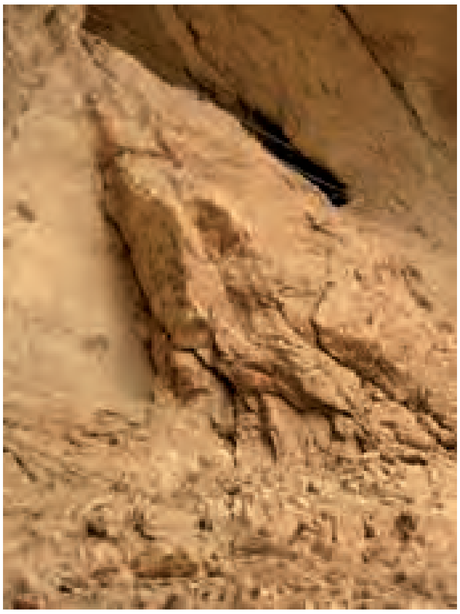


Fig. 18. Remains of the head of the Eastern Buddha (detail with new discontinuities)

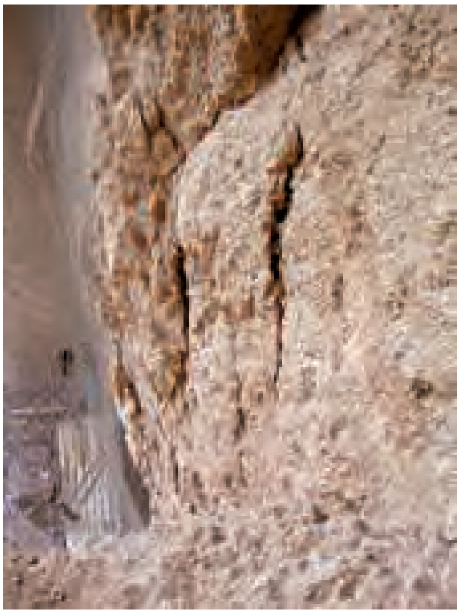


Fig. 21. Left shoulder of the Eastern Buddha (new discontinuities parallel to the back wall)

Fig. 19. Right shoulder of the Small Buddha (new discontinuities parallel to the back wall)

Fig. 22. Left shoulder of the Eastern Buddha (detail of an open joint containing rock debris)

Fig. 23. Discontinuities under the dress pleat

Fig. 24. Cave no. 5 after the explosion

Fig. 25. Caves no. 4 to 6 with new joint in the ceiling

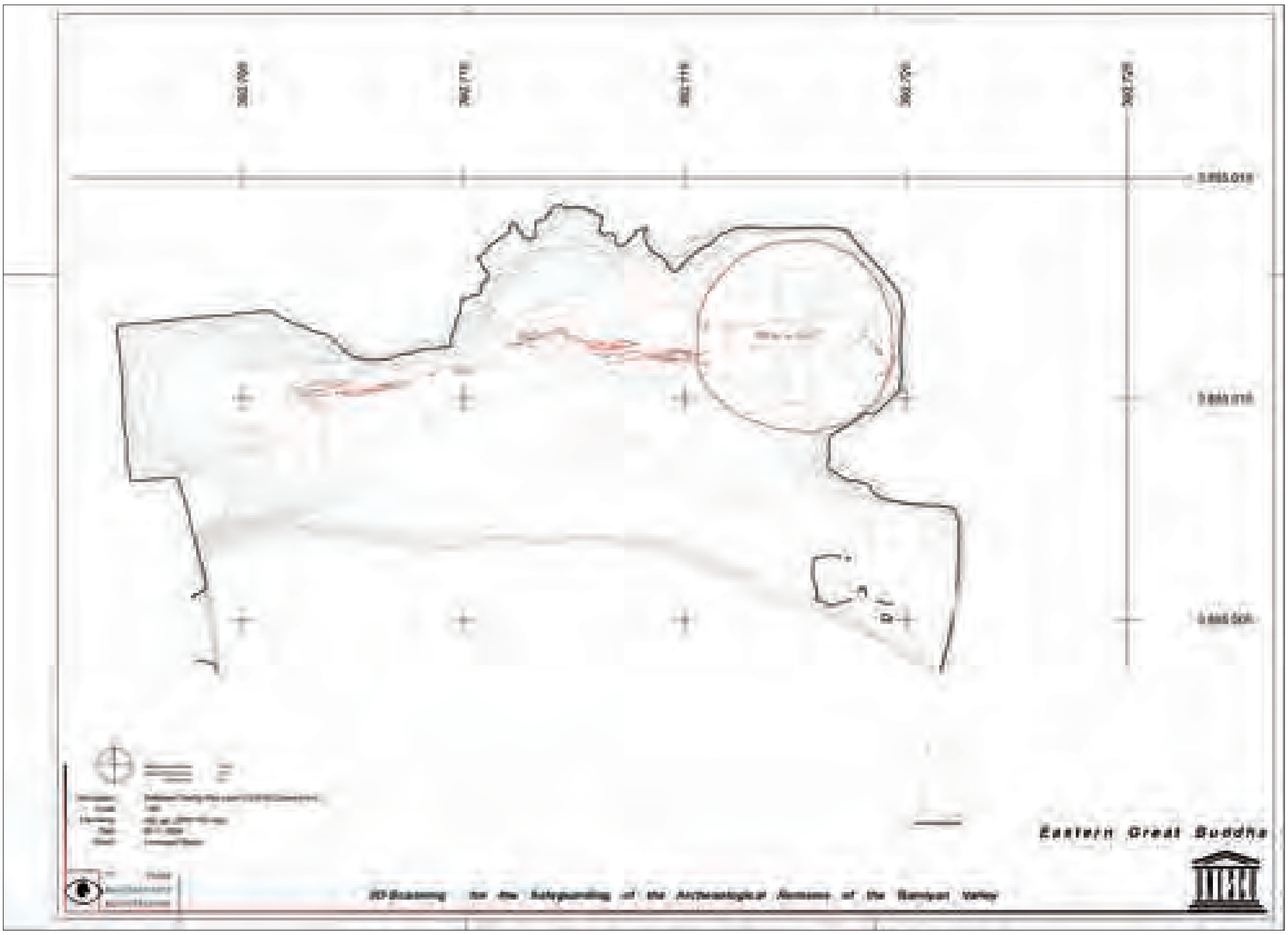


Fig. 26   Steel wire mesh covering the back wall

Fig. 27   Section view of framework

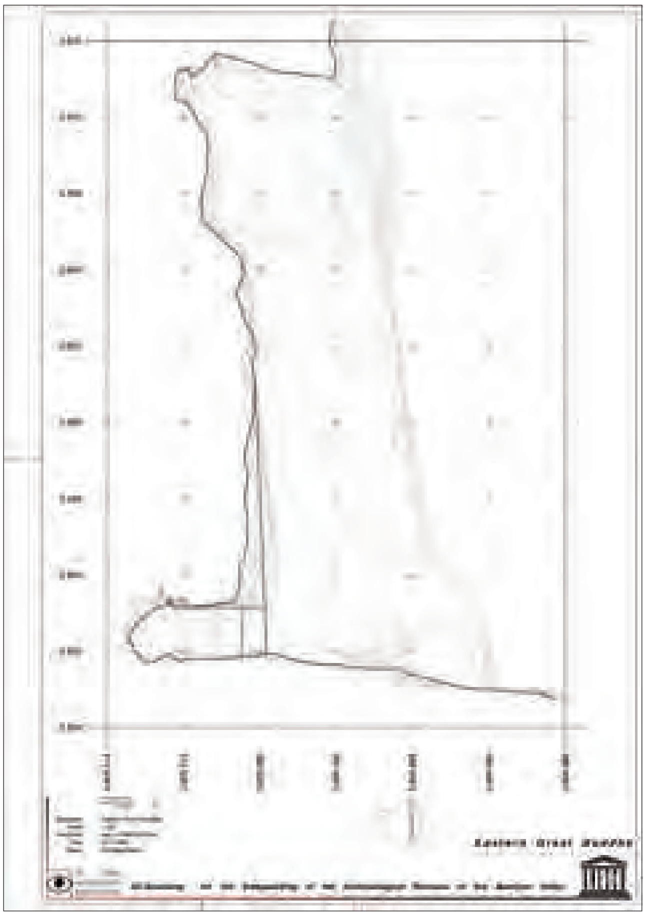


Fig. 28   Front view of framework